

Analysis of pion electroproduction data

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A fit to the existing pion electroproduction data is presented. This work builds upon our previous analyses of pion photoproduction and elastic pion-nucleon scattering over the Delta resonance region. We comment on the extraction of $E_{1+}^{3/2}/M_{1+}^{3/2}$ (E2/M1) and $S_{1+}^{3/2}/M_{1+}^{3/2}$ (S2/M1) ratios, and note that the E2/M1 ratio approaches, and possibly crosses, zero below a Q^2 of 5 (GeV/c)².

1 Introduction

Over the last several years, we have assembled a database containing the existing pion electroproduction data [1] and have made a number of trial fits to this set, exploring possible extensions to the methods we have applied to pion photoproduction [2]. These efforts have intensified now that a flood of new and precise data is becoming available from measurements performed at Jefferson Lab, Mainz and Bonn. Preliminary CLAS data (unpolarized and beam polarization π^0 and π^+ [3] and double polarization π^+ [4]) will soon increase the database size from approximately 10K to 30K points. These new data were taken at CM energies covering mainly the Delta region, and a number of new single- Q^2 [5–7] and Q^2 -dependent [8,9] fits have been carried out, in the hope that a better determination of $\Delta(1232)$ properties might now be possible.

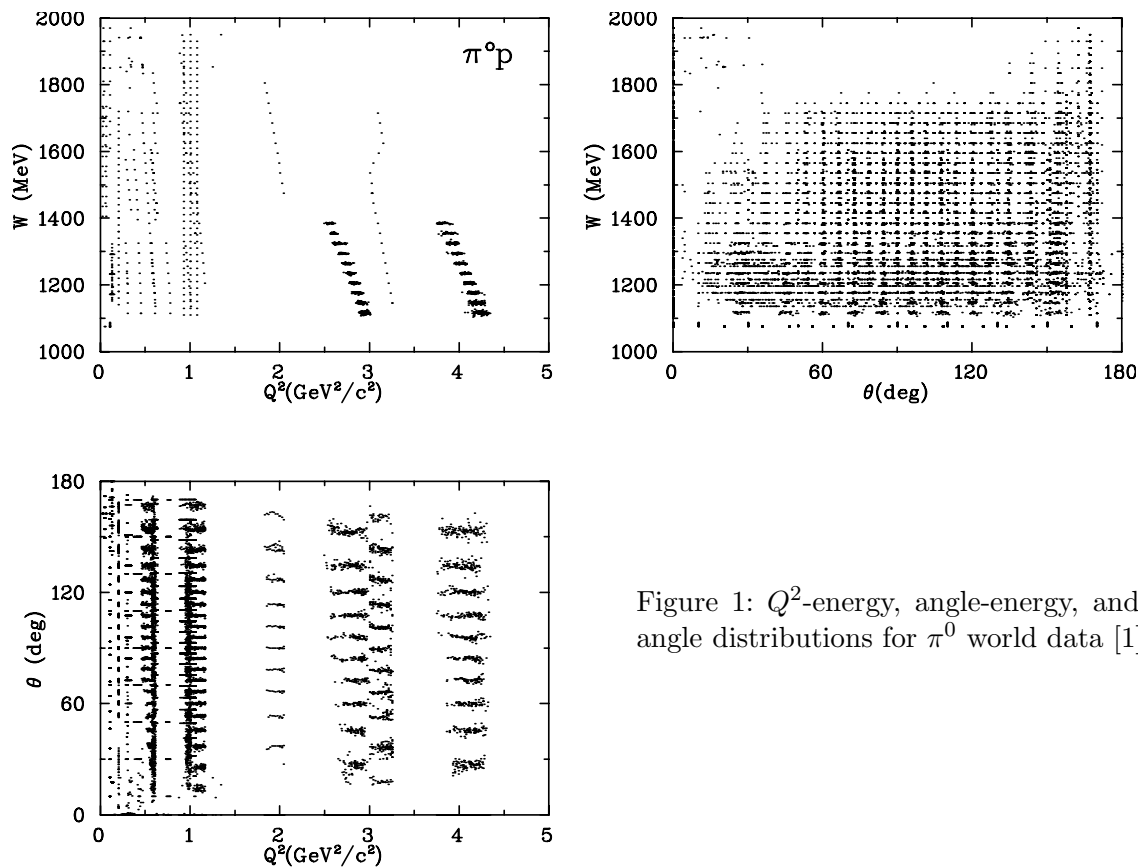


Figure 1: Q^2 -energy, angle-energy, and Q^2 -angle distributions for π^0 world data [1].

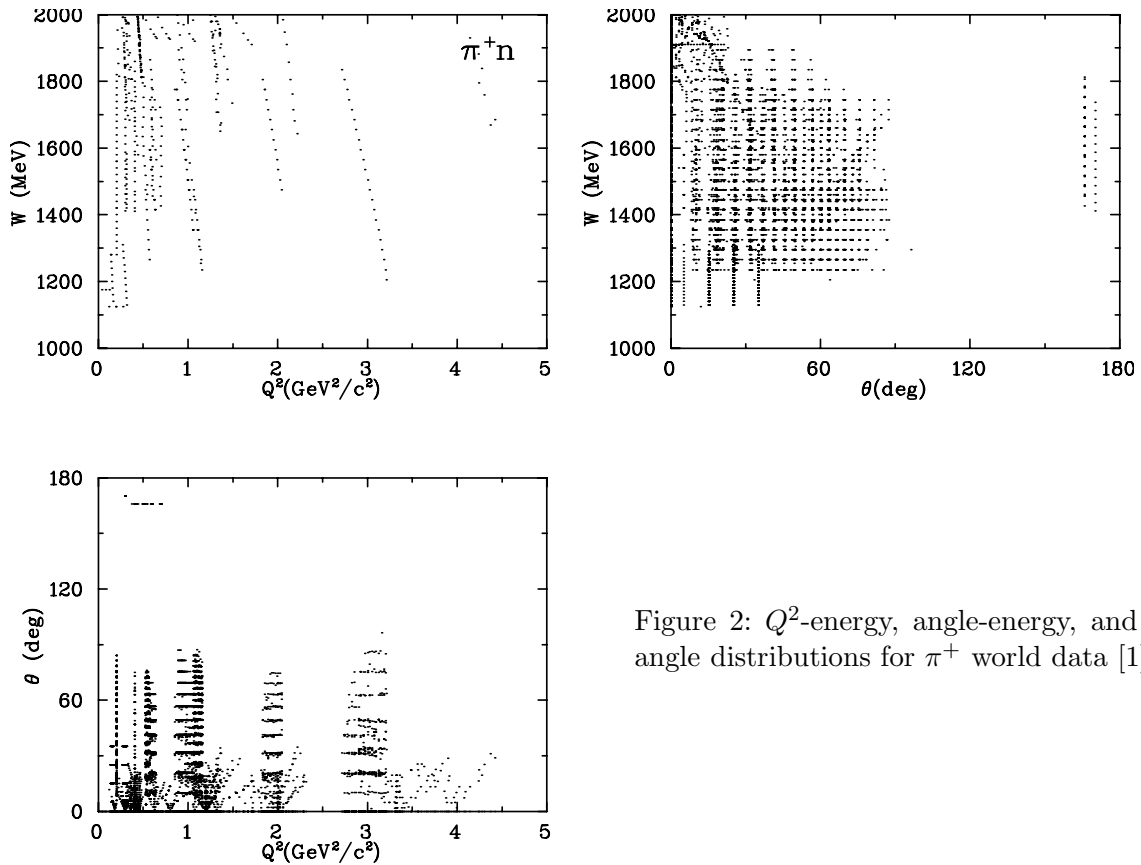


Figure 2: Q^2 -energy, angle-energy, and Q^2 -angle distributions for π^+ world data [1].

These recent determinations have generally confirmed that the E2/M1 ratio remains “small” (compared to the PQCD limit of 100%) at moderate values of Q^2 . However, while some fits [8] find a cross-over to positive values, below 5 $(\text{GeV}/c)^2$, others do not [5,9]. For this reason, we have made a number of fits, both Q^2 -dependent and single- Q^2 , in order to see if a clear trend emerges.

In the following section, we will give an overview of the existing data, and indicate where the abovementioned Jefferson Lab measurements will be added. We will then briefly outline the methods used in our fits. Results for the E2/M1 and S2/M1 ratios will be compared to other recent determinations. Finally, we will attempt to draw some conclusions from this exercise.

2 The Database

It is somewhat more involved to show the data-distribution in electroproduction (a function of W , Q^2 , θ , ϕ , ϵ) than photoproduction (a function of W , θ). In Figs. 1 and 2, we have given 3 projections (with a sum over all ϵ and ϕ values) for both the π^0 and π^+ datasets. This serves to show much of the database is limited to Q^2 values below about 1 $(\text{GeV}/c)^2$, and how little is measured for π^+ electroproduction at backward angles (θ). The preliminary CLAS data are similarly concentrated below 2 $(\text{GeV}/c)^2$, but have much better angular coverage in the π^+ channel.

3 Fitting Strategy

The method we have used to fit electroproduction data is a direct modification of our photoproduction formalism. As in the photoproduction case, correct threshold behavior and Watson’s theorem are built in. Multipoles are parameterized using the form

$$M = (\text{Born} + \alpha_B)(1 + iT_{\pi N}) + \alpha_R T_{\pi N} + (\text{Im}T - T^2)(\alpha_r^H + i\alpha_i^H), \quad (1)$$

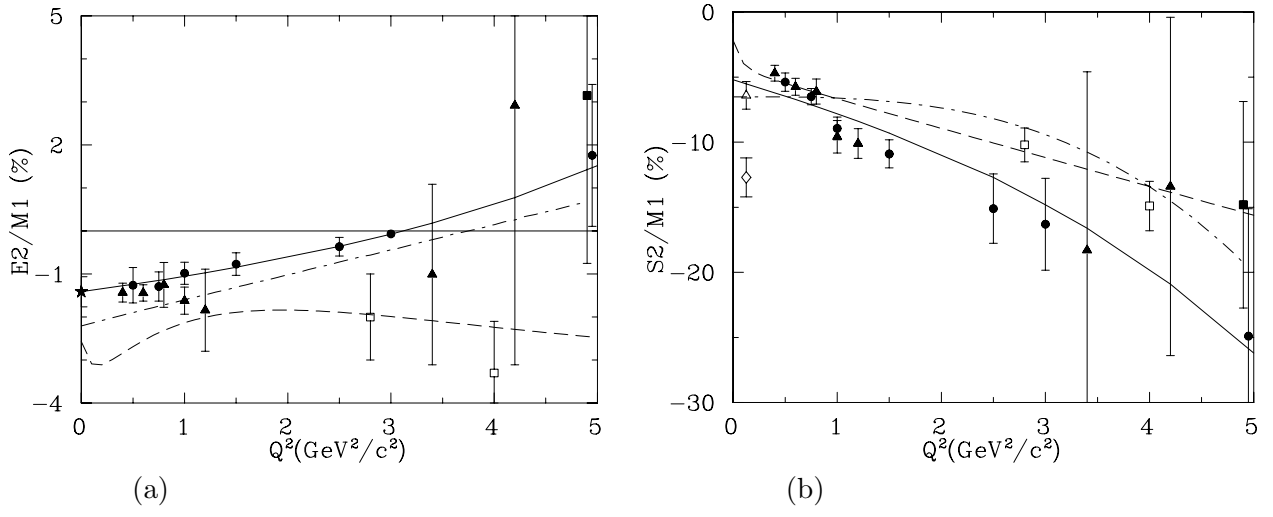


Figure 3: (a) E2/M1 and (b) S2/M1 ratios vs Q^2 . Values were extracted from our QDF (filled circles) using world and preliminary CLAS data (filled square: world data only) and SQS (filled triangle) solutions. Results from Ref. [5] (open squares) are given in both (a) and (b). In addition, in (a), our pion photoproduction result ($Q^2 = 0$) [2] (filled asterisk), and in (b), the data of Refs. [6] (open triangle) and [7] (open diamond) are shown. The solid curves give best-fit results vs the set of QDF solutions. Dash-dotted and dashed curves are from Refs. [8] and [9], respectively.

wherein $T_{\pi N}$ is the πN elastic T-matrix [10] for the πN partial wave connected to a particular multipole, the Born term contains pion and vector-meson exchanges, and α_B , α_R , α_r^H , and α_i^H are phenomenological structure functions. At $Q^2 = 0$, this is the form used in photoproduction. Thus, our present photoproduction analysis is used to anchor the fit at this point. At non-zero Q^2 , the Born terms have built-in Q^2 dependence. Other terms were initially modified by a factor

$$f(Q^2) = \frac{k}{k(Q^2 = 0)} \frac{1}{(1 + Q^2/0.71)^2} e^{-\Lambda Q^2} (1 + \alpha Q^2), \quad (2)$$

where k is the photon CM momentum, Λ is a universal cutoff factor, and α is searched for each multipole. The fit was significantly improved if further variability was allowed in the energy dependence. As a result, an additional parameter was searched (constrained to zero at the resonant point W_R)

$$\alpha Q^2 \rightarrow Q^2 \left(\alpha + \beta \left[\frac{W}{W_R} - 1 \right] \right), \quad (3)$$

W being the CM energy.

As in our photoproduction analysis, we have performed energy/ Q^2 dependent fits over the full kinematic range. We have also fitted data clustered around particular Q^2 values. This allows us to look for trends or problems in the global fit.

4 Comparisons and Conclusions

Our results for Q^2 -dependent (QDF) and single- Q^2 (SQS) fits are summarized in Table 1, for cases including (CLAS) and excluding (NoCLAS) a set of preliminary CLAS data. Results for the E2/M1 and S2/M1 ratios, as functions of Q^2 , are also displayed in Fig. 3. As is evident from Table 1, and Figs. 1 and 2, the database is very sparse above a Q^2 of about 1 (GeV/c) 2 . The single- Q^2 points in this region have correspondingly large uncertainties.

QDF solutions:			SQS solutions:		
$Q_{\min}^2 - Q_{\max}^2$ (GeV/c) ²	χ^2/data	Data	$Q_{\min}^2 - Q_{\max}^2$ (GeV/c) ²	χ^2/data	Data
0.0–5.0	18713/10713	NoCLAS	0.2–0.4	10808/6733	CLAS
0.0–0.5	14647/9304	CLAS	0.4–0.6	17163/11020	CLAS
0.0–0.8	32483/20734	CLAS	0.6–0.8	9882/7497	CLAS
0.0–1.0	37610/24139	CLAS	0.8–1.0	4393/3274	CLAS
0.0–1.5	48294/29820	CLAS	1.0–1.2	8393/4529	CLAS
0.0–2.5	50013/31091	CLAS	2.8–3.4	1318/948	CLAS
0.0–3.0	51572/31837	CLAS	3.8–4.2	831/697	CLAS
0.0–5.0	53828/33209	CLAS			

Table 1: Comparison of Q^2 -dependent (QDF) and single- Q^2 (SQS) solutions.

Most fits were carried out including preliminary CLAS data. A single fit over the full range, excluding the CLAS data, is given for comparison. In Fig. 3, all variants of the fit are included, along with the fits of Refs. [5–7] and the analyses of Refs. [8,9]. Our global fit tends to follow more closely the result of Ref. [8]. Our single- Q^2 fits, though confirming the trend seen in the global fits, have such large uncertainties that they actually overlap with the ratios extracted in Ref. [5]. An improvement will require a more complete coverage of measurements above 1–2 (GeV/c)².

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